Remote bathymetry and current mapping around shore-parallel breakwaters

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ABSTRACT

Surveying very shallow coastal areas, particularly around coastal defences, can be a logistically difficult and time consuming process. A marine-radar based bathymetry mapping technique has been used to remotely map the embayments around a series of shore-parallel breakwaters at Sea Palling on the south east coast of England during the LEACOAST2 project. A comparison between bathymetric maps conducted using conventional survey techniques and the radar based technique is presented together with measurements of tidal currents mapped using the same remote sensing method and compared with ADCP data during a storm event.

BACKGROUND

During a major storm surge in 1953 seven people drowned when the sea overtopped the dunes at Sea Palling in East Anglia. Following that event, a sea wall was built to protect the village from further risk, but in recent years those sea defences began to be undercut by the sea, and a series of nine shore-parallel breakwaters (Figure 1.) were installed in conjunction with beach recharge in an attempt to protect the earlier defences.

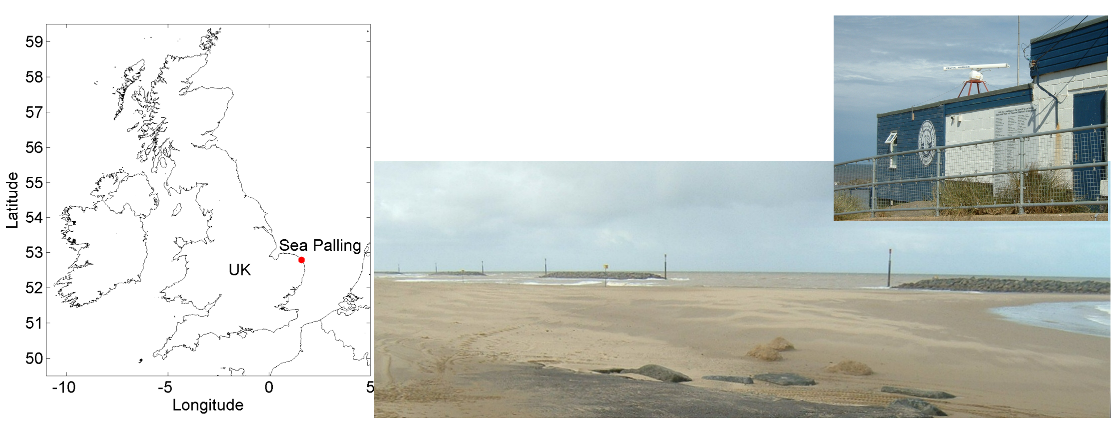

Figure 1. Location map of Sea Palling, a view of the shore-parallel breakwaters and one of the radar sited on the lifeboat station.

These new breakwaters were designed to better retain the sand and hence continue the protection to that part of the coast, but they have performed better than expected at this site and the first breakwater on the northern updrift end of the structures now has a permanent tombolo linking the breakwater to the shore – something that was never intended in the original design and is perhaps due to the unusual tidal regime at the site where maximum currents are coincident with high water. In 2005 The UK Engineering and Physical Sciences Research Council (EPSRC) funded LEACOAST2, a collaborative research project to study the hydrodynamics and sediment processes around these breakwaters that followed on from the earlier LEACOAST project (Dolphin et al, 2004). The aim was to improve the understanding of how such structures interact with their environment and hence improve future design guidelines.

Teams from the Universities of East Anglia, Plymouth and Liverpool and from the Proudman Oceanographic Laboratory (POL) began work in 2006 with a wide range of equipment for monitoring waves, currents and sediment dynamics. In addition, an ARGUS video system was installed to study the nearshore processes and an X-band marine radar for looking over longer ranges. Surveys of the beaches and embayments were conducted at regular intervals both on foot and by boat using an RTK GPS system by the University of East Anglia team.

THE RADAR SYSTEM

A Kelvin Hughes marine X-band radar with a 2.4m rotating antenna was deployed on the roof of the Sea Palling Inshore Lifeboat Station overlooking the offshore breakwaters and associated embayments. This was coupled to a PC based digitisation system of in-house design, allowing 10 minute animations of the sea surface to be recorded automatically every hour to ranges of 4km. Summary images of each record were produced and sent via a broadband link to the POL website so that the status of the system could be monitored via the internet including radar snapshots of the sea surface and time-lapse images that show persistent features very well. Waves tend to be visible on the radar images only when the wave height is larger than about 1m, so in contrast to more conventional surveying techniques this method of mapping is only appropriate during wave events. However, this would allow the bathymetry of an area to be monitored during storms when large changes might be expected.

ANALYSIS

The data analysis works by determining the wavelength and direction of the ocean waves in a small window on the ocean for a range of wave frequencies. The analysis window is of a size chosen to include at least 2 wavelengths (L) of the dominant waves is translated in 2D across the area viewed by the radar. At each point the window of data is processed using Fourier methods to produce a three dimensional wavenumber (k) spectrum (Young et al., 1985). A wave dispersion equation is then fitted to the observed wavenumber spectrum to determine the water depth (d) and 2D current (U) that caused that wave behavior (Bell, 2004). The dispersion equation is based on linear theory with a correction for amplitude dispersion, i.e. the non-linear behavior of large wave in shallow water which travel faster than linear theory alone can predict (Hedges, 1976). There is also a correction for currents to account for the Doppler shift the waves traveling on a mean current:

Water depth $$d = \frac{1}{k}\left(\tanh^{-1} \frac{(\omega - k.U)^2}{gk} \right) - Z$$

where wavenumber $k = \frac{2\pi}{L}$, angular frequency $\omega = 2\pi f$

and $Z = 0.5H$ for monochromatic waves (Booij, 1981), or $Z = 0.35H_S$ for spectral waves.

As the analysis approach is based on Fourier methods the wave behaviour must be assumed to be uniform within that small window. The analysis window is translated across the study area and hence a map of the inferred water depth and current is produced.

In order for such maps to be useful in the longer term, they must be related to a local datum, and so the tide level must be subtracted from the derived water depth maps to produce a map that is relative to the desired datum. In this case the pressure records for the experiment are still being analysed, and so the surge component of the tide was identified from the nearest UK National Tide and Sea Level Facility gauges at Cromer and Lowestoft, and this surge component added to the predicted tide levels for Sea Palling to provide the vertical reference.

RESULTS

Hourly records spanning a 60 hour period during a wave event from 31st October to the 2nd November 2006 from the Sea Palling radar were processed. A snapshot from one such radar record is shown in Figure 2.

The Hydrodynamic conditions measured at the time are shown in Figure 3. Surge data are derived from the National Tidal and Sea Level Facility (NTSLF) gauges at Cromer and Lowestoft, the nearest main ports, and have been added to tidal predictions for the site. Wave and current data were derived from an ADCP in the study area.

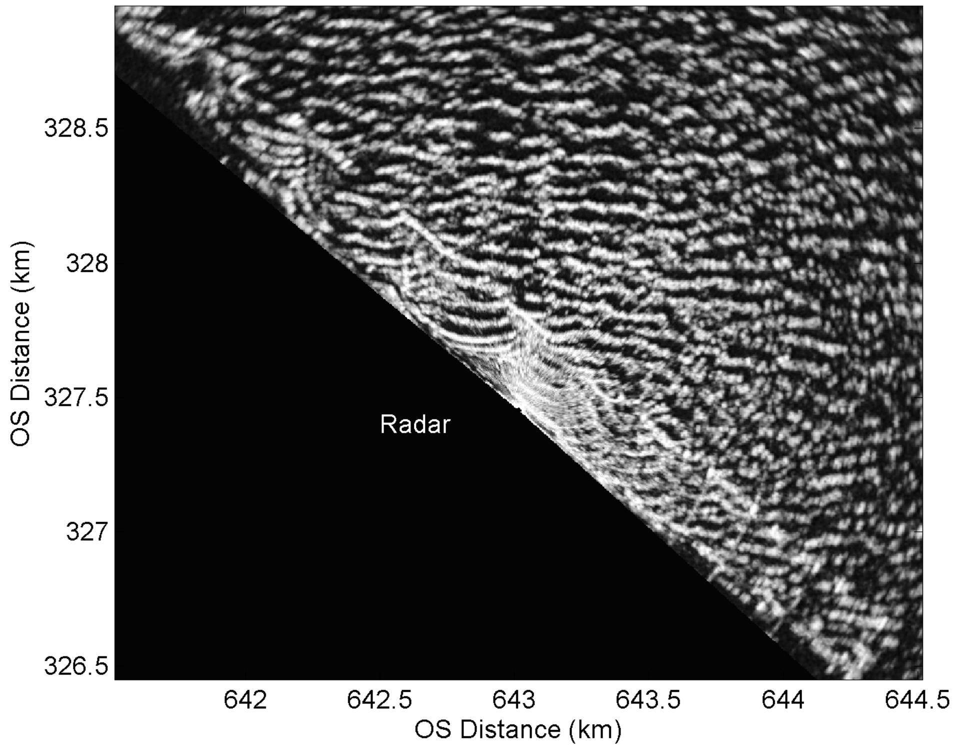

Figure 2. A radar snapshot from 23:00, 31st October 2006. Light colors indicate strong radar backscatter as on a conventional radar PPI display.

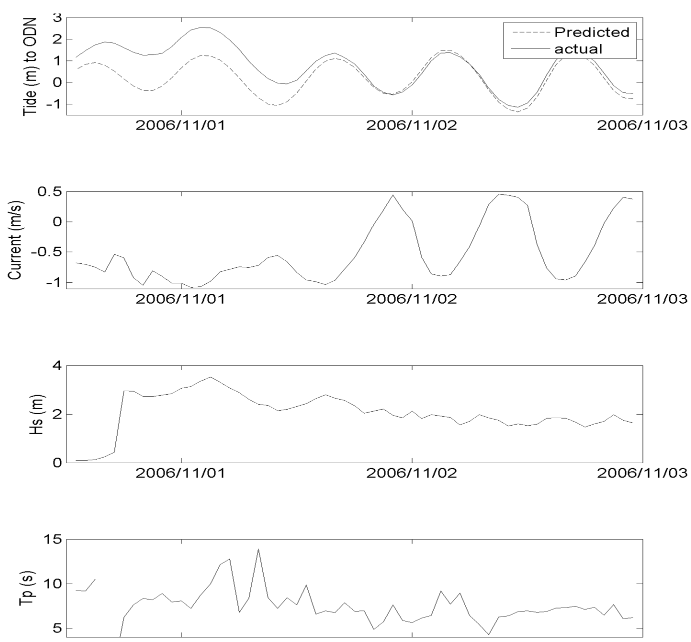

Figure 3. Tide, longshore current (+ve flow to NW (ebb)), Hs and Tp during the analysis period.

In order to highlight the capabilities of the radar technique in areas of complex bathymetry around the breakwaters and embayments a window size of only 120m was selected which was translated across the study area at a quarter of this spacing, hence giving measurements on a 30m grid spacing. The author would usually select a much larger window size of several hundred metres for areas of less complex bathymetry but it was interesting in this case to see how far the technique could be pushed in such a challenging environment.

The gridded survey data are shown in Figure 4. The breakwaters are shown in heavy black lines, the thin black lines indicate the survey track lines and the white lines denote long-shore and cross-shore transects examined in detail in the results section. The white spot marked F1 refers to an instrument frame that included an Acoustic Doppler Current Profiler for monitoring currents and waves.

The results from each of these records have been corrected to Ordinance Datum Newlyn (ODN) using the tide predictions plus the observed surge component and combined to give the bathymetric map shown in Figure 5.

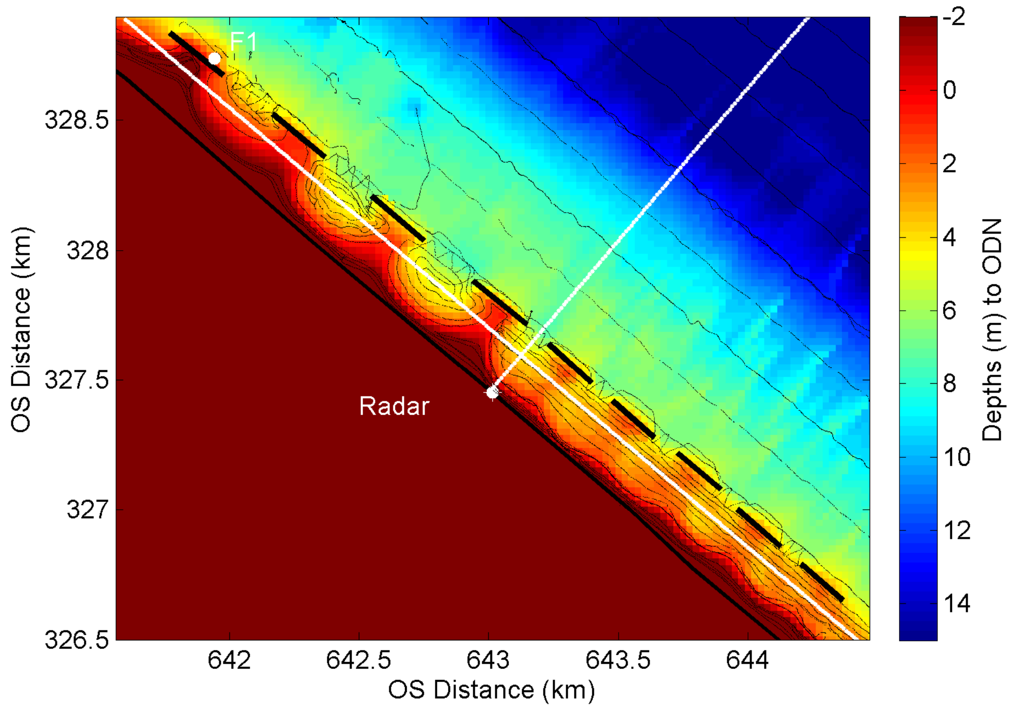

Figure 4. Gridded survey data recorded 3 weeks after the wave event. Breakwaters are shown in heavy black lines, the thin black lines indicate the survey track lines and the white lines denote analysis transects. The white spot marked F1 refers to an instrument frame including an ADCP.

Comparison of the two maps shows a clear agreement both in overall pattern and in absolute elevation. Some subtle discrepancies can be observed, particularly offshore of the breakwaters where submerged dune features are faintly visible. Most of these discrepancies are thought to be due to the gridding of insufficiently dense survey data since track lines in this area are 200m apart.

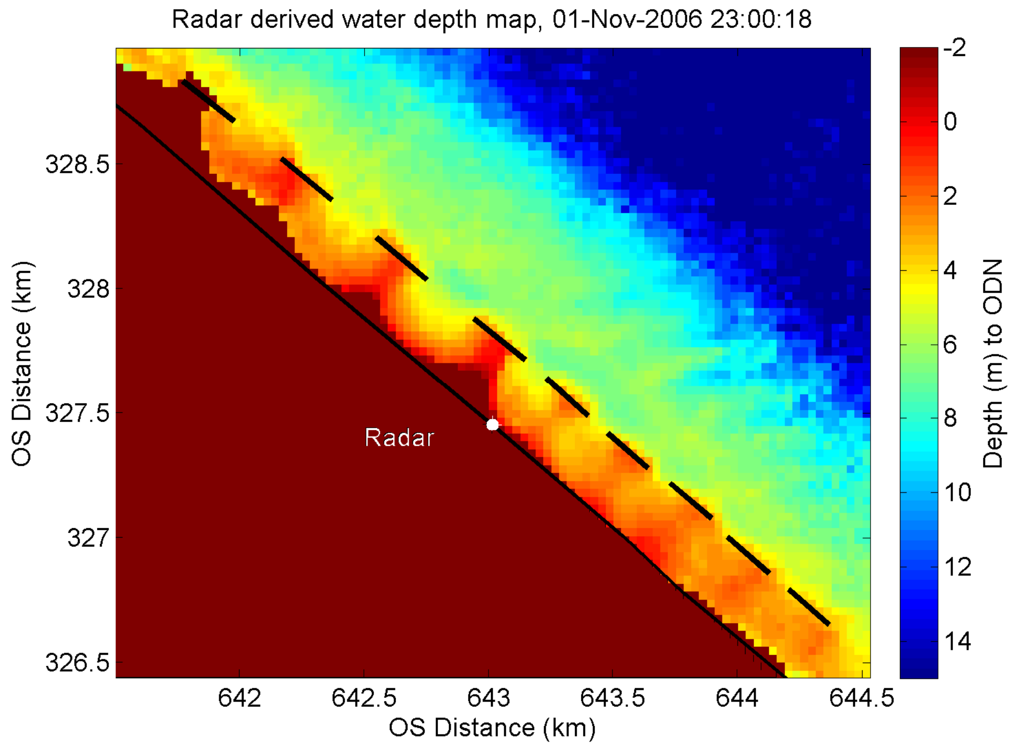

Figure 5. Radar derived bathymetric map referred to Ordinance Datum Newlyn.

Comparisons with the survey data can be made by plotting long-shore and cross-shore transects from both survey and radar derived bathymetries, the locations of which are shown in white in Figure 4.

The depths along the two transects from the survey and radar are shown in Figure 6. These show clear agreement, particularly in picking out the salients linked to each breakwater. Discrepancies in the long-shore transect are thought to be due to changes in beach morphology between the wave event and the time of the survey which was performed during calm weather three weeks later. Discrepancies with the cross-shore transect are thought to be due to insufficiently dense survey data in the offshore region, i.e. survey track lines that were 200m apart in the cross-shore direction. Accuracies are generally with 1m of the survey data and usually considerably better. It is difficult to make accurate statistical comparisons in this respect as survey data are recorded at different times to the radar, usually weeks apart, during which time shallow areas are prone to a degree of natural variability in morphology.

The currents were also calculated during the analysis, and the radar derived currents corresponding to a location close to frame F1 which contained the ADCP used for comparison are shown in Figure 6.

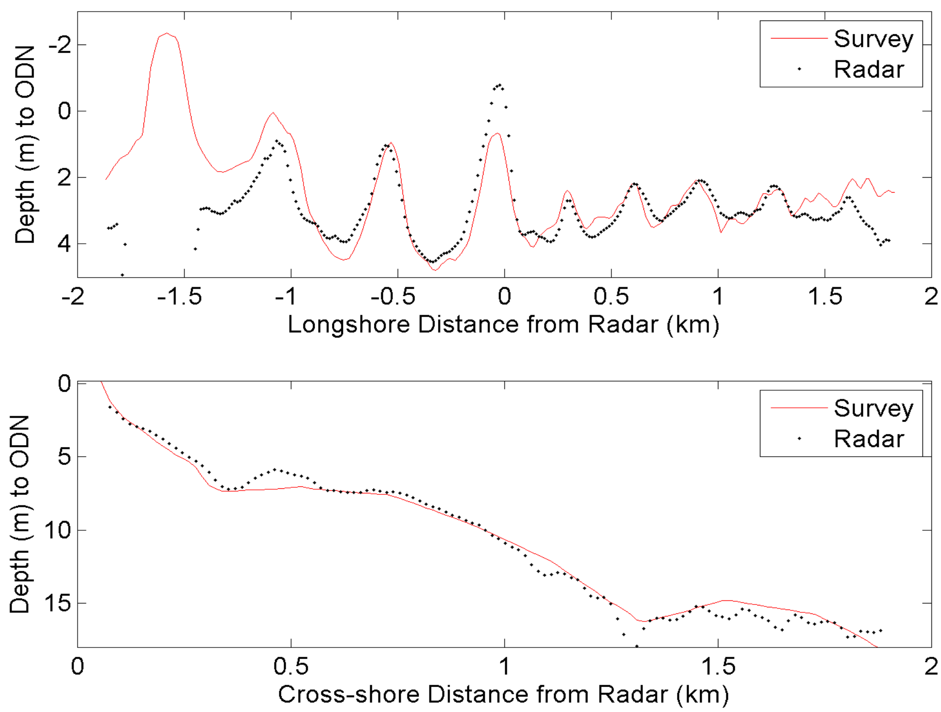

Figure 5. Long-shore and cross-shore transects from the survey (solid line) and radar derived bathymetry (dotted line).

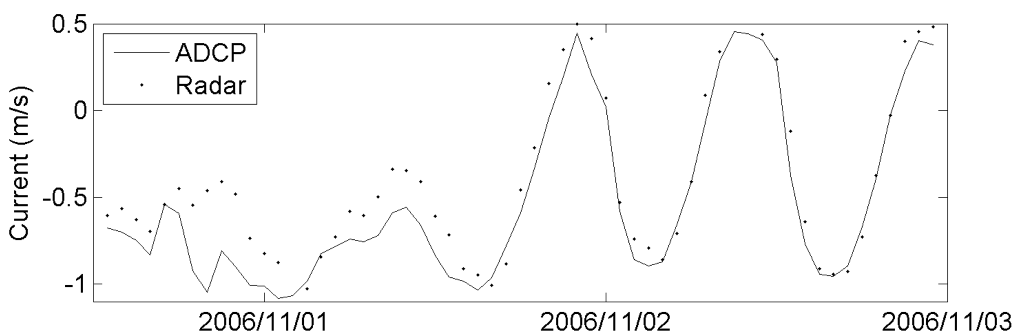

Figure 6. A comparison currents measured using an ADCP (solid line) and radar (dotted line). +ve currents flow to the north west, -ve to the south east.

These currents are clearly very similar, with only slight discrepancies during the height of the storm, probably due to the fact that the analysis window from which the radar derived current was calculated was slightly seaward of the frame location in order to avoid having the breakwater in the analysis window.

The currents at this location close to the shore did not reverse with the tide during the height of the storm – an observation consistent with several other current meters deployed around the study site. This was initially attributed to the additional south-easterly current from the storm surge. However, inspection of the currents further offshore of the breakwaters and measured using the radar system indicate that the offshore currents did in fact reverse with the tide. This suggests that the longshore tidal current close the shore was overridden during the height of the storm by wave induced currents generated by the storm waves impacting the shore from the north, a fact that would not have been revealed without the use of the radar as all in-situ current meters were located very close to the breakwaters.

CONCLUSIONS

The ability to map complex areas of bathymetry using data recorded from a standard marine radar has been clearly demonstrated. While this technique will never be able to match the accuracy of modern survey techniques, its strength lies in the ability to monitor large areas of shallow water as often as there are sufficient waves to be seen on the radar. Since the method uses the shoaling of waves to derive water depths, it is generally unsuitable for deep (>20m) areas but could be used operationally to monitor the movement of sandbanks in areas where this might be of commercial importance. One example might be a port area located in an area of mobile sand banks where the radar derived maps could give an early warning that a sand bank was about to migrate into a navigation channel. It has also been demonstrated that currents may be mapped using the same technique, and that these compare well with ADCP data.

ACKNOWLEDGEMENTS

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